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ART. II.—*Contact Phenomena in the Morang Hills, Victoria.*

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Abstract.

The Morang Hills are 20 miles N.N.E. of Melbourne, and consist of a small inlier of Silurian sediments and Devonian granodiorite in an area of Tertiary Newer Volcanic basalt flows. The sediments are predominantly mudstones and shales and form a thin cover above the granodiorite. They show progressive metamorphism through spotted muscovite hornfels, and biotite-hornfels to relatively coarse-grained cordierite-biotite-hornfels as the granitic contact is approached. The north-eastern part of the contact is occupied by a sillimanite-andalusite-hornfels, rich in orthoclase.

Along its margin, and particularly at its contact with the sillimanite-andalusite hornfels, the granodiorite, which is otherwise normal, passes into a potash-rich phase, studded with giant phenocrysts of orthoclase. The extra potash appears to be derived from assimilation of the potash-rich contact rocks at a time when the magma had come to rest, and lost much of its original fluidity.

Introduction.

The Morang Hills are situated about 20 miles N.N.E. of Melbourne, and 3 miles N.E. of Epping. The railway line to Whittlesea turns eastward between Epping and South Morang in order to by-pass them (fig. 1). The hills rise to a height of 850 feet above sea-level, and consist of Silurian sediments, intruded and thermally metamorphosed by a small stock of (?) Devonian granodiorite. The metamorphic zone extends for a quarter to half a mile from the granodiorite contact (fig. 2), and the marginal granodiorite is characterised by giant phenocrysts of orthoclase, which occur only sparsely in the interior of the stock.

The Palaeozoic rocks form an inlier 4 miles long (N.-S.) by 3 miles broad, in an area of Newer Volcanic basalt flows, and rise about 300 feet above the surrounding plain, the surface of which is broken by small "stony rises." The basalt flows came from the north, obliterating the pre-existing streams.

The Morang Hills have the form of two north-south ridges separated by a south-trending valley a quarter to half a mile wide, and 250 to 300 feet deep. The western, or Quarry Hill, ridge is 100 to 150 feet higher than the eastern ridge, and consists of hard, dense hornfels, forming a cover about 200 feet thick over the granodiorite, which is exposed in a quarry on the south-eastern side of the ridge (fig. 2). The eastern ridge consists of granodiorite, fringed by less resistant metamorphosed sediments. The short and intermittent creeks draining the hills have built alluvial flats where they debouch on to the basalt plains. The main streams of the area are the Darebin Creek, on the west, and the Plenty River on the east. The Darebin Creek, over part of its course, follows the boundary of the Silurian sediments with the basalt.

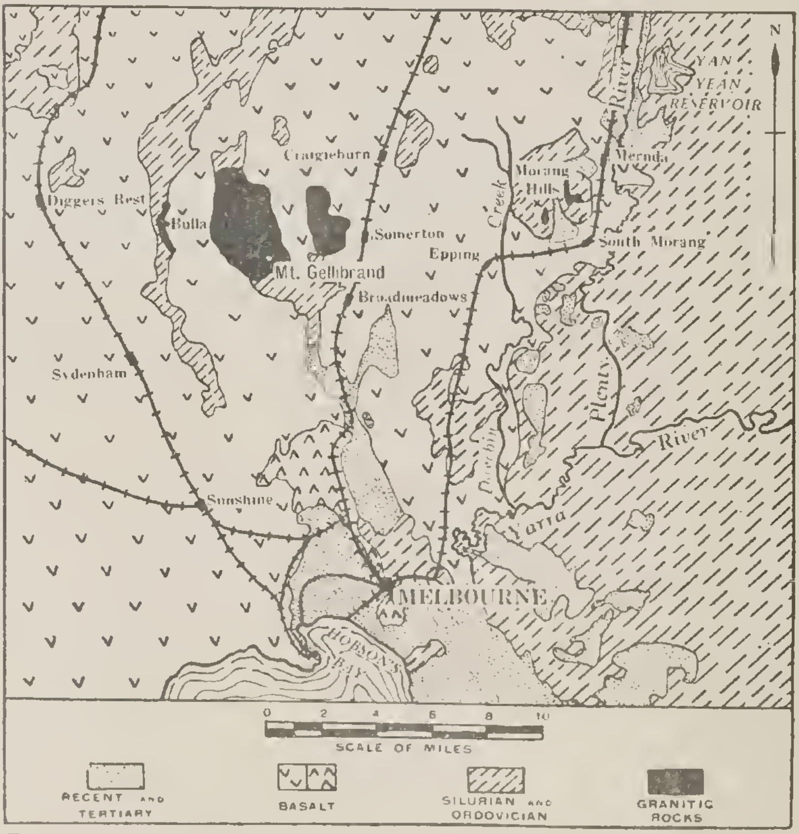

FIG. 1.—Locality Map showing the position of the Quarry Hill Area and Neighbouring Granite Rocks outcropping at Bulla and Mt. Gellibrand. Drawn, with modifications, from the Geological Map of South Central Victoria (Handbook for Victoria, 1935).

The area was first geologically surveyed by Etheridge in 1868, in connection with the preparation of Quarter Sheet No. 2 N.E. Jutson (1910) referred to it briefly in his study of the Plenty River, and a brief note on the Morang granodiorite has been published by Howitt (1936). Kenny (1937) reported upon the gold-bearing alluvial lead at South Morang, and Skeats and James (1937) compared the stony rises of the basalt plains with those of the Colac District.

Interest in the area attached chiefly to the metamorphic changes induced in the Silurian sediments, and to the hybrid origin of the margin of the intrusion.

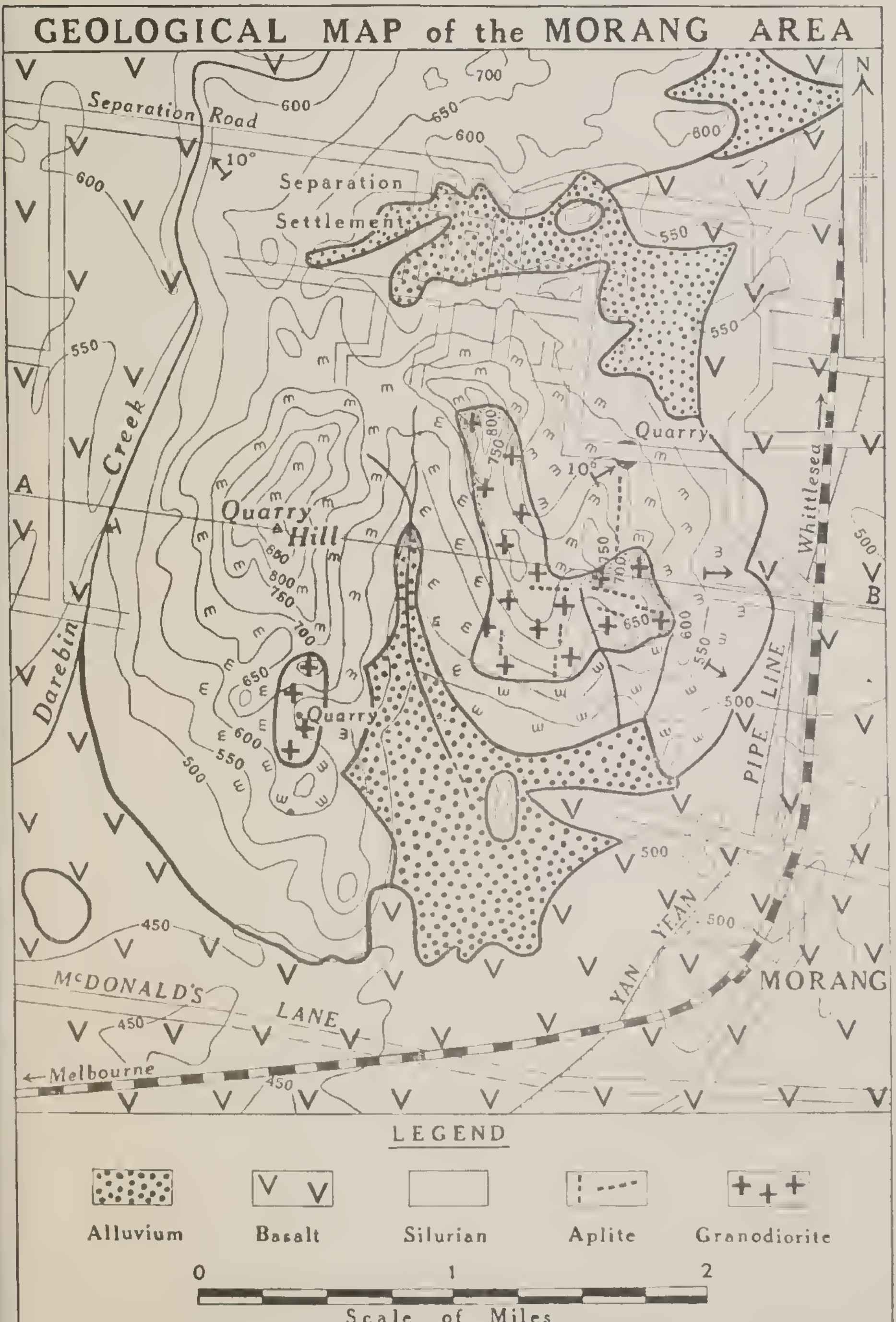

Fig. 2.—Geological Map of the Morang Area, based on Military Survey Sheet of Yan Yean and Quarter Sheet No. 2 N.E. of the Victorian Geological Survey.

The Silurian Sediments.

The Silurian sediments consist of finely-bedded mudstones and shales, with an occasional interbedded sandstone band. Their geological relationships are largely masked by soil and hillwash, but such dips as could be found indicate that they occur in a dome-like structure with outward dips of from 10°-20° (fig. 2). The best exposures are in the Country Roads Board quarry, to the north-east of the eastern outcrop of granodiorite, and on Separation-road near the bridge over Darebin Creek. No fossils have been found in the Morang Hills, but there can be little doubt that they represent a continuation of lithologically similar, fossiliferous rocks of Silurian age which outcrop a few miles to the north (Jutson, 1908).

Contact Metamorphism.

Mudstones and Shales.

The successive stages in the metamorphism of the original argillaceous shales and mudstones are best seen between Darebin Creek and the western granodiorite outcrop. The unaltered sediments are fine-grained rocks consisting of varying proportions of quartz, chlorite, and sericitic material, with lesser amounts of accessory iron ores, and detrital zircon, rutile and sphene. In the outer aureole, the first signs of metamorphic change are induration of the sediments and the appearance of small wisps of secondary mica. With increased recrystallization, the amount of secondary mica formed increases, and the mica tends to segregate, so that the rocks appear spotted. The spots are rich in pale-green and white mica, and are spherical to ovoid in shape. They have ill-defined boundaries, and merge into the surrounding matrix. Closer to the contact, but still at about 300 yards or more from it, the spotted texture becomes pronounced, owing to the increased size of the secondary mica plates. In places the spots consist largely of limonite, formed from the weathering of iron ores associated with the segregated mica plates. Generally, however, and particularly in the more arenaceous rocks, they are made up chiefly of clear white or pale yellowish-green mica, and are separated by interstitial areas rich in quartz. According to Tilley (1924, p. 28), such spots in the contact rocks of an outer aureole are due to the selective aggregation of directional minerals under the influence of interstitial solutions, derived in part from the sediment and possibly in part from the magma.

Zone of Biotite Development.

Closer to the contact, but in some parts of the aureole at distances of almost 300 yards from it, biotite begins to make its appearance as small plates, some of which are bleb-like and are included in quartz crystals. The quartz grains of the sediments have grown larger, and the white mica now forms laths and plates of muscovite. The appearance of biotite marks a significant change in the nature of the metamorphism, from one involving only recrystallization of existing minerals, to one involving chemical reconstruction of the rock, and the formation of new minerals (Tilley, 1924, p. 29). The biotite is formed from chemical reactions involving the chlorite, sericitic material, iron oxides, rutile and silica of the mudstones and shales, which now lose much of their residual structures, and pass into more or less spotted hornfels. At this stage, the titanium minerals in the sediments have recrystallized to form numerous minute and scattered crystals of rutile, with sporadic crystals of brookite, and rare anatase. The detrital sphene has recrystallized to form clusters and strings of granular sphene, and occasional small prisms of tourmaline make their appearance. These indicate slight pneumatolysis. The iron ores and zircons remain unchanged.

Zone of Cordierite Development.

Still closer to the contact cordierite makes its appearance. The zone of cordierite development is usually from 200 to 250 yards from the contact, and in one place is a quarter of a mile from an observed contact. This exceptional occurrence is found at Country Roads Board quarry, and suggests that the granodiorite is close to the surface at this locality.

The rocks are still spotted in this zone of the aureole, but the spots now consist of poikiloblastic cordierite crystals, which are replacing the original micaceous spots. The cordierite crystals have irregular outlines, and show sixfold twinning. They contain innumerable inclusions, consisting of iron-ore dust, minute flakes of biotite and plates of muscovite. The inclusions are often confined to the centres of the cordierite crystals, the margins of the crystals being clear. The matrix of the rock consists of numerous laths and small plates of biotite and granular crystals of quartz, together with abundant minute crystals of rutile, lesser brookite and sphene, and some waterworn zircons. The rocks may be classed as cordierite-biotite hornfels, with fine-grained granoblastic texture. The biotite, though still present only as minute crystals, has passed the bleb stage. The abundance of cordierite, and the absence of andalusite from this zone is probably due to the high chlorite content of the original sediments (Tilley, 1924, p. 31). Where rocks in this zone were originally rich in sericitic material, they have formed sericite-biotite-quartz hornfels, comparable with those developed at Bulla (Tattam, 1925, p. 233), and lacking in cordierite.

With more intense metamorphism, the cordierite hornfels and biotite-quartz hornfels become somewhat coarser-grained, and their iron ore grains become fringed with biotite as they approach the actual contact; but no additional new minerals make their appearance, other than occasional grains of diopside.

Sillimanite-Andalusite Rocks.

Along the northern contact of the bulge on the eastern side of the more easterly granodiorite outcrop, varieties of thermally altered rocks occur which have not been observed elsewhere in the aureole. They appear to have been formed from argillaceous sediments which were rich in sericite, but much poorer in chlorite than the sediments which gave rise to the cordierite hornfels or the biotite-quartz hornfels. Most conspicuous among them is a porphyroblastic rock, in which the spots, which are up to 5 mm. across, consist of felted masses of sillimanite fibres, accompanied by plates of colourless muscovite and occasional flakes of biotite. Within the spots are found occasional frayed and embayed crystals of andalusite. These inclusions, in conjunction with the commonly idioblastic form of the spots, indicates that the spots once consisted entirely of andalusite, and that with progressive metamorphism the andalusite has been largely converted into sillimanite. Orthoclase is present as numerous granular crystals and xenoblasts in the matrix. Tilley (1924, p. 60) has shown that orthoclase can be formed from interaction of sericite and silica (quartz), with the production of andalusite as a by-product, or by the reaction of biotite with quartz. The latter reaction, however, involves the simultaneous formation of cordierite, and since no cordierite has been found in the sillimanite-andalusite rocks at Morang, it is thought that the orthoclase and the original andalusite developed from original sericite. Any soda in the sericite has formed occasional crystals of oligoclase, or has entered into solid solution in the orthoclase. The orthoclase and oligoclase occasionally occur intergrown in diablastic structures.

The alkali content of the rock is K_2O 5·19, Na_2O 1·99. The potash content is high, but not unduly high for mudstones, as compared with other analysed Palaeozoic mudstones and slates from Victoria (Howitt, 1923). The soda content, however, is unusually high for a mudstone so rich in potash, so that some proportion of the alkalis may have been introduced from the granodiorite. If this occurred, it is likely that soda rather than potash was introduced, since, as shown later, the granodiorite magma appears to have been saturated with soda, but under-saturated with respect to potash.

Brown and reddish-brown biotite, quartz, and, occasionally, tourmaline, are the other chief constituents of the sillimanite-andalusite hornfels. The biotite has been partially altered to pale-coloured chlorite, with the precipitation of rutile as long needles and as sagenitic webs. The accessory minerals present are waterworn zircons, with occasional rutile, brookite and sphene crystals, and in some specimens, abundant iron ores.

Associated with this distinctive spotted hornfels are arenaceous and muscovite hornfelses, of variable grain size, which characteristically contain abundant limonite, derived from the fine-grained iron ores of the original rock. They are soft, crumbly rocks, which are much more readily eroded than the dense, quartz-biotite hornfels and cordierite hornfels of the Quarry Hill ridge.

Arenaceous Sediments.

Arenaceous sediments, though present in the Morang aureole, are of such restricted occurrence that it is impossible to trace the successive stages of their metamorphism. In general, the hornfelses derived from them resemble those derived from the more sandy argillaceous rocks, but contain more quartz. Some approach quartzites in composition and consist of a mosaic of interlocking quartz crystals, with occasional interstitial areas of greyish-brown, crypto-crystalline material which appears to be a mixture of sericite and chlorite. Others, originally richer in chlorite and sericite, contain wisps and plates of muscovite, and of pale-green and pale-brown mica. A feature of the arenaceous hornfelses is that they almost completely lack the grains of iron ore that are so abundant in many of the altered argillaceous rocks. Rutile, brookite, and sphene are similarly lacking, though occasionally detrital crystals of these minerals are found associated with well-defined strings of waterworn zircon crystals lying along an original bedding plane. Another difference from the argillaceous hornfelses is the small number of spotted structures in the arenaceous hornfels. When spots are present, they consist of clots of muscovite plates.

Along the eastern ridge, scattered boulders of brecciated, fine-grained, arenaceous hornfels have been found both north and south of the eastern bulge in the granodiorite outcrop. The angular fragments of hornfels, together with occasional fragments of quartz are cemented together by limonite, and some of the hornfels fragments are traversed by small quartz veins. The presence of the small quartz veins suggests that the brecciation occurred in the interval between metamorphism and the late stages of consolidation of the granodiorite.

Grain Size.

The hornfelses generally show an increase in grain size as the granodiorite junction is approached. Thus, in a micaceous variety, 300 yards from the contact, the quartz grains average about 0·04 mm. across; in a spotted hornfels, 200 yards from the contact, they are 0·08 mm. across; in an arenaceous hornfels, 100 yards from the contact, they are 0·1 mm. across; while in the sillimanite-andalusite hornfels at the contact the average size of the quartz grains is between 0·4 and 0·8 mm. across. For comparison, it may be noted that quartz crystals in the granodiorite average 2·5 mm. in diameter, and are up to 4 mm. across in the porphyritic marginal granodiorite, while in the xenoliths they range between 0·8 and 1·5 mm. across. The rocks close to the granodiorite are not invariably coarse-grained, however. Some are little coarser-grained than the sediments from which they are derived, and according to Tilley (1924, p. 64) neither differences in original grain size nor differences in composition can account for these grain size anomalies.

Laminated Hornfels.

The increase in grain size with more intense metamorphism arises from an increased range of diffusion, and this leads to a corresponding destruction of residual or palimpsest structures. Where the original sediments were finely bedded or current-bedded, with alternating beds of variable composition, the hornfels derived from them show a corresponding lamination, bands of arenaceous hornfels alternating with bands of argillaceous hornfels. There may be as many as 30 such laminae to the inch, and in some of the laminae lamellar minerals like biotite and muscovite are arranged in sub-parallel fashion. This type of structure persists into the zone of cordierite development, but close to the contact the complete recrystallization and reconstitution of the rocks has generally destroyed all traces of it. It is best seen in weathered hornfels in the Country Roads Board quarry (fig. 3) and on Quarry Hill (fig. 4).

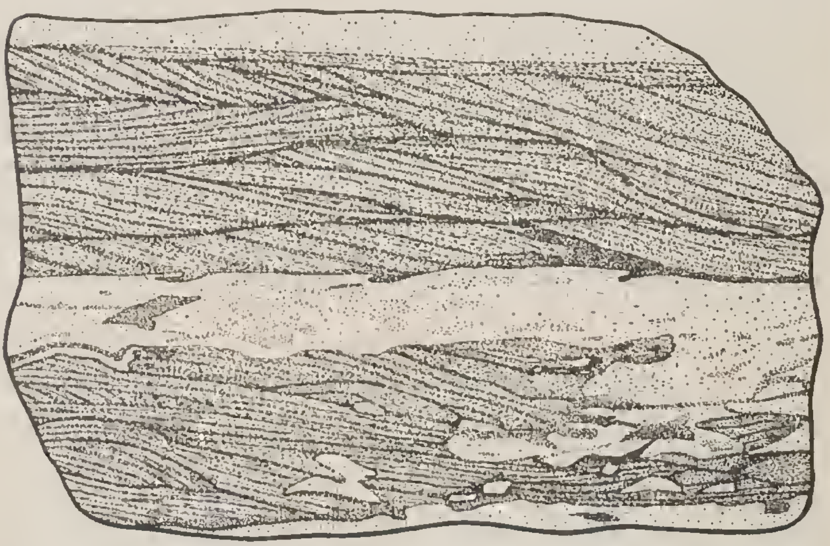

Fig. 3.—Sketch of Laminated Hornfels showing Preserved Cross-bedding Structures. From Country Roads Board Quarry.

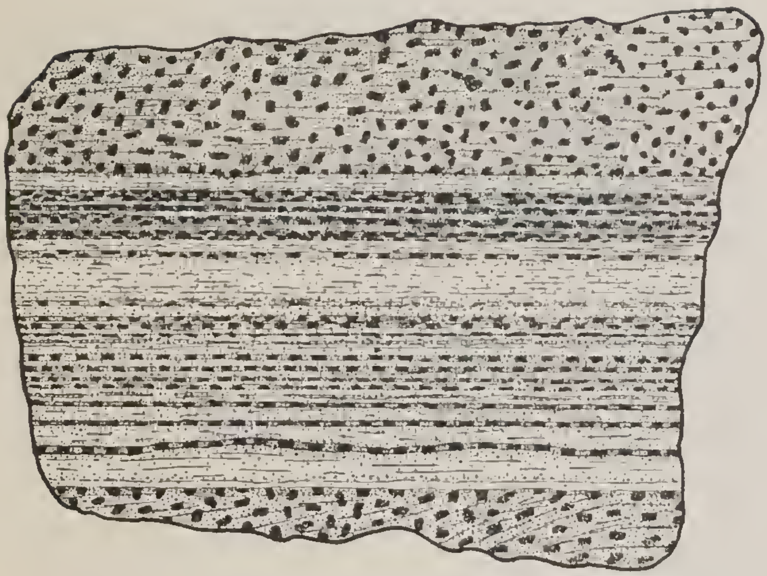

Fig. 4.—Sketch of Banded Hornfels from Quarry Hill, showing Bedding Structures preserved by narrow alternating bands of Spotted Hornfels and Arenaceous Hornfels.

Remarks on the Contact Metamorphic Zones.

The contact aureole at Morang resembles in many respects that at Bulla (James, 1920; Tattam, 1925), but there are some points of difference. The temperature of the Morang intrusion was not very high, since hydrated minerals are present in the contact rocks, and persist right up to the granodiorite junctions. The contact rocks at Morang, moreover, are all free-silica, non-calcic hornfels, and the characteristic rocks of the aureole are argillaceous types. As a result, spinellids are absent, and corundum is rare. Corundum, armoured about with mica, has been observed in only one section. The biotite "beards" fringing the ilmenite grains indicate that this mineral contributed to the formation of biotite, much as in some igneous rocks. Small amounts of lime in the original sediments have recrystallized to form a few minute grains of pale-green diopside and occasional crystals of oligoclase. The original detrital sphene in the partially metamorphosed sediments recrystallized to form sphene granules in the more intensely altered rocks; and the abundant apatite in the hornfelses is largely derived in the same way from detrital apatite, but some phosphorus seems to have been introduced from the magma, since close to the contact the apatite occasionally occurs in small veinlets. Tourmaline is only sparsely developed, and topaz is doubtfully present in small amount, showing that the inner contact rocks have been subjected to only slight pneumatolysis.

Xenoliths in the Granodiorite.

Xenoliths derived from the sedimentary rocks are relatively numerous in the more easterly exposure of granodiorite, but not in its porphyritic margin, despite the prevalence of xenocrysts and products of assimilation in this zone. The xenoliths range in size from less than an inch up to 18 inches in diameter. They show various stages of granitisation (Baker, 1936), and are sometimes foliated, the foliation resulting from an initial variation in composition of alternating lamellae such as gave rise to the laminated hornfelses.

In the early stages of reconstitution, the xenoliths consist of granular rocks not very different from the hornfels close to the contact. In some instances, the invasion of material from the granodiorite magma has caused the formation of phenocrysts of oligoclase and poikiliths of orthoclase and quartz. With advancing reconstitution, coarser-grained patches develop in the originally fine-grained xenoliths, and these coarse-grained areas spread until the whole xenolith has a granitic texture. The porphyritic intermediate stages of the transition commonly resemble biotite-rhyodacites, both in texture and in mineral composition.

The completely reconstituted xenoliths can be divided into three groups according to their mineral composition:—

(1) orthoclase-biotite-quartz rocks, with little or no plagioclase;

(2) oligoclase-biotite-quartz rocks, with little or no orthoclase; and

(3) oligoclase-hornblende-biotite-quartz rocks, in which there is little or no orthoclase.

The xenoliths of group 1 represent potash-rich contact rocks which have been further recrystallized, without marked metasomatic alteration. Those of group 2 appear to have been derived from similar rocks, but have undergone metasomatic changes, soda and lime from the granodiorite magma having been substituted for the potash of the original hornfels. In the group 3 xenoliths, metasomatic alteration has gone further, and the biotite has also been affected. In the least reconstituted rocks, the biotite first appeared as small blebs, which with increasing granitisation, grew first into small laths, which collected into decussate patches, and then "coalesced" or were "welded" into large plates. Finally, the biotite commenced to react with the lime brought in by the invading magmatic solutions, and changed over to hornblende. At the same time, the titanium in the biotite was thrown down as sphene. The hornblende formed by the reaction grew into large plates showing sieve structure, and enclosing remnants of the original biotite, and the precipitated sphene crystals. The K_2O of the biotite presumably passed into the granodiorite magma along with the K_2O from the original orthoclase.

Where clots of ferromagnesian minerals came into direct contact with the granodiorite magma, they tended to react with it and form pink almandine garnets (Edwards, 1936). Zircon is the only mineral in the original sediments which resisted recrystallization, and well-rounded, waterworn zircons are found in each class of xenolith. In the completely reconstituted xenoliths, however, idiomorphic zircons surrounded by pleochroic haloes are also present, as inclusions in both the hornblende and the biotite, and such zircons were presumably introduced from the granodiorite magma. A common feature of all the xenoliths is the abundance of rods and needles of apatite, which are included in later-formed minerals, and represent recrystallized lime phosphate from the original sediments. A second generation of apatite crystals, appearing in some xenoliths in the form of much larger crystals represents lime phosphate introduced from magmatic solutions soaking through the xenoliths.

Granodiorite.

The granodiorite is a mesocratic, medium to fine-grained rock, with occasional phenocrysts of orthoclase up to ½-inch across. It consists of allotriomorphic and interstitial quartz grains, zoned and twinned oligoclase showing partial alteration to sericite, partly kaolinised orthoclase, biotite, and occasionally hornblende. The hornblende is derived from the assimilation of xenoliths, in which it was formed during their chemical reconstitution by a substitution of lime from the magma for the potash of original biotite. The biotite is occasionally chloritised, and associated with calcite. It carries inclusions of zircon surrounded by intense pleochroic haloes, and of ilmenite and small apatite crystals. The apatite also occurs as large individual crystals not enclosed in biotite. The biotite also contains inclusions of a pale yellowish-green weakly pleochroic micaceous mineral, which is surrounded by pronounced pleochroic haloes 0.02 mm. wide. The individual inclusions are too small for precise determination, but the mineral appears to be one of the radioactive, light-coloured micas (Johannsen, 1914, p. 323). It has a maximum absorption in the same direction as the biotite, but has a lower refractive index. Its birefringence is high, and it shows anomalous extinction. Orthite is present occasionally (Baker, 1937, p. 56, fig. 8). Small amounts of pyrrhotite and molybdenite occur in joint planes in the quarry on the western ridge.

The heavy minerals are listed in Table 1, where they are compared with the heavy minerals of the neighbouring granitic rocks of Mount Gellibrand and Bulla. The heavy mineral suites of the three rocks are closely comparable, particularly with respect to the essential heavy minerals, and the primary accessory minerals. The separation of the heavy minerals was carried out in bromoform of specific gravity 2.88, in the manner described by Baker (1942, p. 201).

A chemical analysis of the rock (Table 2, No. 2) shows that it is a typical granodiorite, and that it closely resembles in composition the granodiorites of Bulla and Mount Gellibrand (Table 2, Nos. 3 and 4).

Jointing in the granite is not conspicuous. The most prominent planes are vertical and strike N.W.-S.E. Subsidiary joints strike E.-W. and N.10°E. Tors formed on weathering are small, rarely exceeding 10 feet in height.

TABLE 1.—Showing heavy mineral index numbers and assemblages of three related granodioritic rocks in South-Central Victoria.

—	South Morang (West Outcrop).	Bulla.	Mt. Gellibrand, Broadmeadows.
Index Number	11·68	10·71	9·42
Actinolite	..	..	V
Apatite (colourless)	a	a	a
Apatite (pale yellowish-green)	V	o	r
Biotite	a	A	A
Brookite	X	V	..
Chlorite	o	A	o
Corundum	V	..	..
Epidote	X	..	r
Garnet	o	o	V
Gold	..	..	V
Hematite	r	..	..
Hornblende	o	..	..
Ilmenite	o	r	o
Magnetite	..	..	V
Orthite	X	..	..
Rutile	X	..	o
Sulphides	o	r	o
Tourmaline	V	..	V
White Mica	C	C	o
Zircon (colourless)	C	C	C
Zircon (pale yellow)	V	V	C
Zircon (inclusions in)	C	r	o

Key.—A—very abundant; a—abudant; C—common; o—occasional; r—rare; V—very rare; X—recorded from thin sections.

The heavy mineral assemblages of neighbouring granodiorites in South-Central Victoria (Table 1) were obtained from the separation of crushed, fresh, representative rock in bromoform of specific gravity 2.88 and their index numbers obtained in the manner described elsewhere (Baker, 1942, p. 201). The brookite noted in the Bulla granodiorite is recorded from one grain only of that mineral, while minerals marked X in Table 1 only appeared in thin sections of rocks from certain portions of the outcrops.

TABLE 2.—Showing chemical analyses of neighbouring granodioritic rocks in South-Central Victoria.

—	I.	II.	III.	IV.	V.
SiO_2	66·30	69·17	66·13	67·75	..
Al_2O_3	16·42	15·95	16·83	16·11	..
Fe_2O_3	0·52	0·88	1·11	0·50	..
FeO	3·00	3·64	4·17	4·00	..
MgO	1·05	1·12	1·83	0·79	..
CaO	1·85	3·04	3·26	2·68	..
Na_2O	2·65	2·64	2·25	2·60	1·99
K_2O	6·00	3·07	3·14	3·42	5·19
H_2O	0·42	0·36	1·91	1·16	..
TiO_2	0·44	0·77	tr.	0·85	..
MnO	0·05	0·03	0·07	tr.	..
P_2O_5	1·12	0·02	tr.	0·09	..
Cl	..	..	..	..	..
Total ..	99·82	100·69	100·70	99·95	..
Sp. Gr. ..	2·67	2·66	2·68	2·68	..

I.—Porphyritic marginal phase of the granodiorite, South Morang. (Analyst: A. B. Edwards)

II.—Quarry Hill granodiorite, South Morang. (Analyst: F. J. Watson).

III.—Bulla granodiorite. (Analyst: F. J. Watson) (James, A., 1920).

IV.—Mt. Gellibrand "adamellite", Broadmeadows. (Analyst: H. C. Richards) (Stillwell, F. L., 1911).

V.—Metamorphosed Silurian shale adjacent to porphyritic granodiorite.

PORPHYRITIC MARGINAL PHASE OF THE GRANODIORITE.

The marginal portion of the granodiorite in the eastern outcrop is pronouncedly porphyritic, the phenocrysts consisting of anhedral orthoclase crystals which are up to 3 inches long and 1 to 2 inches wide.

This border phase appears to be purely local as shown in fig. 2, but it may extend along the roof and walls of the stock as suggested in fig. 5.

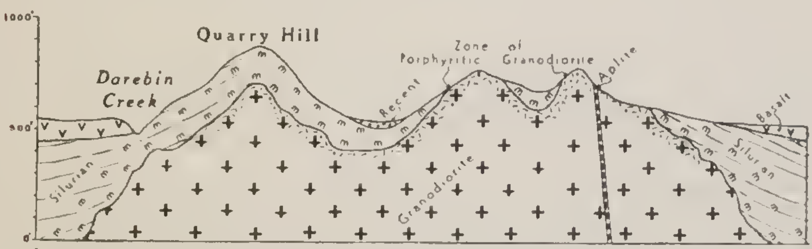

Fig. 5.—Geological sketch section through Quarry Hill, showing probable space form of the granodiorite, porphyritic zone and relationship to the invaded Silurian country rock.

The orthoclase phenocrysts show a random arrangement, and are not at all corroded. They contain lamellar perthite intergrowths of albite, and poikilitically enclose crystals of biotite, oligoclase, quartz, zircon, apatite, ilmenite, muscovite, andalusite and garnet. The andalusite is derived from the disintegration of xenoliths of the sillimanite-andalusite hornfels, while the garnet is a reaction product of the granodiorite magma with the ferromagnesians of the xenoliths (Edwards, 1936, p. 44).

The groundmass of the border phase consists of contaminated granodiorite. In it oligoclase predominates over orthoclase, and associated with these minerals are biotite, muscovite, garnet, brookite, andalusite, corundum and diopside. In addition, there are numerous remnants of granitised xenoliths. Much of the biotite is a reddish-brown colour, and resembles that in the hornfels, from which, presumably, it is derived, as also are certain quartz grains containing clouds of dust-like inclusions. In parts of the marginal zone, abundant muscovite is mainly derived from the assimilation of muscovite hornfels at the adjacent contact, as is the andalusite and corundum. These portions of the granodiorite also contain a pale green mica, reddish-brown biotite, and xenocrysts of material identical with the sillimanite-mica idioblasts found in the nearby sillimanite-andalusite hornfels. The pale-green mica has been formed by the bleaching of biotite, and the titanium, which was taken up by the biotite during its development under thermal metamorphism, has been thrown down as rutile needles in the cleavages, where it forms sagenitic webs.

A chemical analysis of the marginal phase (Table 2, No. 1), shows that it is distinctly richer in potash, and in phosphorus, than the normal granodiorite (Table 2, No. 2), and that it is poorer in lime, but otherwise has many features in common with it.

The enrichment in potash can have developed in either of two ways. It may represent a marginal concentration of potash-rich residual magma, or it may have arisen through the assimilation of potash-rich sediments by a magma almost at rest. The abundance of xenocrystic matter in the marginal phase, and the established potassic character of the adjacent contact sediments leaves little doubt that part at least of the potash was derived from this second source.

The replacement of orthoclase by oligoclase, and of biotite by hornblende, in certain of the xenoliths in the granodiorite away from the porphyritic margin indicates that the granodiorite magma as a whole was more or less undersaturated with respect to K_2O, since it could take additional K_2O into solution without immediately reprecipitating it as potash minerals. Occasional coarse crystals of orthoclase do occur through the main mass of granodiorite, suggesting that the degree of undersaturation was only slight, but they are neither as large nor as abundant as those in the marginal zone. Presumably, therefore, the magma was sufficiently fluid for the potash obtained from the xenoliths to be more or less evenly distributed through the magma by diffusion and by convection currents.

The size of the phenocrysts of orthoclase in the marginal zone, coupled with their late formation, indicates that they must have crystallized rapidly. This establishes that the marginal zone, unlike the core magma, was saturated with K_2O, and that addition of extra K_2O from the assimilated xenoliths led to its rapid re-precipitation as orthoclase.

As long as xenoliths could migrate into the interior of the granodiorite stock, their potash content could be dispersed through a considerable volume of magma, and the increase in potash at any one point would be slight, and without any marked effect; but with a cessation of such movement, any potash added would accumulate in the limited volume of magma adjacent to the contact, where saturation would soon develop, and lead to re-precipitation of the potash.

In the marginal zone, the lack of parallel arrangement of the orthoclase crystals, and the abundance of xenocrystic "strew" indicates that the magma was not subject to convectional currents or differential movements, and had lost the fluidity which enabled earlier formed xenoliths to sink or be swept out into the interior of the stock, so that there was no strong force which would sweep away the products of the assimilation that was clearly in progress. Moreover, the apparent loss of fluidity would suggest a restricted range and rate of diffusion for dissolved substances such as potash, which would then develop local over-saturation and precipitate as large phenocrysts of orthoclase. Such a cessation of movement, and reduction of fluidity might be expected to develop at the margin as the stock cooled.

Dykes and Veins.

Occasional aplite veins from 1 to 20 feet wide traverse the granodiorite, and more rarely the contact rocks. They can be traced for only short distances. Aplite also forms occasional patches and stringers threading through the granodiorite. The aplites have fine to coarse saccharoidal textures, and consist chiefly of orthoclase, interlocked with quartz crystals, and with lesser amounts of idiomorphic oligoclase, scattered plates and radial aggregates of muscovite, occasional plates of altered biotite, and rare crystals of ilmenite, apatite and zircon. Fine-grained, graphic pegmatite of much the same composition occurs as scattered boulders near the eastern margin of the eastern granodiorite contact, and small veins of quartz, seldom more than 3 inches wide, are occasionally present. Small amounts of orthoclase are associated with the quartz in vughs in these veins.

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